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Electric dipole transitions for Mg XI ($Z = 12$)

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Abstract : Wavelengths, oscillator strengths and transition probabilities for electric dipole transition (E1) between $1snl$ ($1 \leq n \leq 9$, $0 \leq l \leq 3$), $2s^2$, $2s2p$, $2s3s$, $2s3p$, $2p^2$, $2p3s$ and $2p3p$ states for heliumlike magnesium (Mg XI) have been calculated. For these calculations multiconfiguration Hartree-Fock approximation within the framework Breit Pauli relativistic corrections have been used. Results obtained have been compared with other experimental and theoretical results.

Keywords : MCHF method, relativistic corrections, wavelengths, oscillator strengths, transition probabilities.

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1. Introduction

Oscillator strength data are of great importance in thermonuclear fusion research; knowledge of excitation cross sections (proportional to the oscillator strengths) is essential for the determination of radiation losses in tokomak plasmas as well as for spectroscopic diagnostic. Transition rates or probabilities of heliumlike ions are important in practical applications such as the design of X-ray lasers and the diagnosis of high temperature plasmas and X-ray sources. Precise knowledge of the decay rate is important in the study of astrophysical between charged particles. The analysis of spectra necessitates the knowledge of the different physical processes responsible for the level population (dielectronic capture, inner-shell excitation and ionization, radiative recombination *etc.*). The relative importance of these processes is determined by calculation of the atomic parameters. The quality of the interpretation of the observations is very sensitive to the accuracy of these atomic parameters. The helium and heliumlike ions, being the simplest many electron systems, traditionally serve as an important testing ground for investigation of theoretical methods. The need for reliable

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data concerning highly ionized atoms has increased because of studies of the solar corona, solar flares and the diagnosis of high temperature plasmas and of X-ray sources.

Magnesium is one of the most abundant elements in universe, its abundance being ~2.7 × 10^{-5} smaller than that of hydrogen. Observations of Mg XI are important as line ratios for this ion, are density sensitive in the range of interest for active regions. Prominent lines of Mg XI were identified by Sawyer *et al* [1]. Walker and Rugge [2] observed lines of the principal series of heliumlike magnesium. Peacock *et al* [3] presented satellite spectra for He-like ions laser produced plasmas. The intercombination lines $1s3p\ ^3P_1$–$1s^2\ ^1S_0$ of Mg XI were determined for the X-ray spectroscopy of multicharged ions in the spectra of laser produced plasmas by Boiko *et al* [4,5]. Armour *et al* [6] observed X-ray wavelengths of magnesium transitions. The first analysis of high resolution solar Mg XI X-ray spectra was carried out by Siarkowski *et al* and Bromboszcz *et al* [7–9]. An analysis of Mg XI spectra from two non-flaring solar active regions was presented to determine electron temperature and ion abundance [10]. Klein *et al* [11] measured ultraviolet transitions in foil-excited beams of magnesium Verner *et al* [12] listed atomic data for absorption lines from the ground level. Stefanelli *et al* [13] measured radiative lifetime of $1s2s\ ^3S_1$ level in heliumlike magnesium using electron-beam ion trap technique.

The some atomic properties for Mg XI were calculated using perturbation theory [14–20], quantum electrodynamics theory [21–26], MCDF [27] and relativistic random phase approximation [28–30]. Mewe and Schrijver [31] presented detailed calculations of the rate and coefficients for heliumlike ions. Drake [32,33] performed unified relativistic theory for frequencies and transition rates and presented spontaneous two-photon decay rates. The wavelengths of all transitions of $1snl$-$1sn'l'$ for heliumlike spectra were predicted (Z = 11–18) by Martin [34]. Johnson and Sapirstein [35] computed the relativistic pair correlation energies for He-like ions. Derevianko and Johnson [36] calculated two-photon decay of two metastable states of heliumlike ions. Safronova and Johnson [37] presented energy levels and autoionizing rates using the Z expansion method.

The electric dipole transitions which are strongest transitions have been widely studied. In this paper, wavelengths, weighted oscillator strengths and transition probabilities for electric dipole transition (E1) between some excited states for heliumlike magnesium (Mg XI) have been calculated. Oscillator strengths, transition probabilities or lifetimes have been frequently worked for lower states of Mg XI. Some data for these can be found in, for example, [38–41]. In this work we have also investigated highly excited states for Mg XI. The goal of this study has considered correlation and relativistic effects for highly ionized magnesium using Multiconfiguration Hartree-Fock (MCHF) approximation within framework Breit-Pauli relativistic corrections [42]. $1snl$ ($1 \le n \le 9$, $0 \le l \le 3$), $2s^2$, $2s2p$, $2s3s$, $2s3p$, $2p^2$, $2p3s$ and $2p3p$ configurations are selected

to consider core-core and core-valance correlation effects. In addition the calculations are extended to the calculation of wavelengths, weighted oscillator strengths, and transition probabilities using the MCHF atomic-structure package [43].

2. Method of calculation

In this method, the wavefunction is expanded as a linear combination of orthonormal configuration state functions (CSFs)

$$\Psi(\gamma LS) - \sum_{i=1}^{M} c_i \Phi(\gamma_i LS), \quad \sum_{i=1}^{M} c_i^2 - 1, \tag{1}$$

where $\Phi(\gamma_i LS)$, γ_i and c_i denote configuration state function in LS coupling, configurations and mixing (or expansion) coefficients, respectively. The energy expansion becomes

$$\varepsilon(\gamma LS) = \sum_{i=1}^{M}\sum_{i=1}^{M} c_i c_j \left\langle \Phi(\gamma_i LS)|H|\Phi(\gamma_j LS)\right\rangle = \sum_{i=1}^{M} c_i^2 H_{ii} + 2\sum_{i>j}^{M} c_i c_j H_{ij}, \tag{2}$$

where

$$H_{ij} = \left\langle \Phi(\gamma_i LS)|H|\Phi(\gamma_j LS)\right\rangle \tag{3}$$

and H is nonrelativistic Hamiltonian.

In the Breit-Pauli approximation, the wavefunction, Ψ, is a linear combination of CSFs of the form

$$\Psi(\gamma J) = \sum_{LS}\sum_{j} c_j(LS)\Phi(\gamma_j LSJ)\,. \tag{4}$$

The CSFs, $\Phi(\gamma_j LSJ)$, for a configuration and coupling γ_j, term LS, and total angular momenta L and S coupled to J, are built from a basis of one-electron spin-orbitals,

$$\phi_{nlm_l m_s} = \frac{1}{r} P_{nl}(r) Y_{lm_l}(\theta,\varphi)\chi_{m_s}. \tag{5}$$

The expansion coefficients, $c_j(LSJ)$, and corresponding energy, $E(LSJ)$, are an eigenvector and eigenvalue, respectively, of the interacting matrix of these CSFs as defined by the Breit-Pauli Hamiltonian. The Breit-Pauli Hamiltonian can be written in the form

$$H_{BP} = H_{NR} + H_{RS} + H_{FS} \tag{6}$$

where H_{NR} is nonrelativistic many-electron Hamiltonian, H_{RS} is relativistic shift operator including mass correction, the one- and two-body Darwin terms, spin-spin contact and orbit-orbit terms and H_{FS} is fine structure operator including nuclear spin-orbit, spin-other-orbit and spin-spin terms. In the calculations, the radial functions are taken from nonrelativistic MCHF run and only expansion coefficients are optimized. Thus the matrix

eigenvalue problem becomes

$$Hc = Ec \tag{7}$$

where H is the Hamiltonian matrix with elements

$$H_{ij} = \left\langle \gamma_i L_i S_i J M_J \left| H_{BP} \right| \gamma_j L_j S_j J M_j \right\rangle . \tag{8}$$

The Breit-Pauli Hamiltonian is a first-order perturbation correction to the nonrelativistic Hamiltonian.

The line strength between two levels can be written as

$$S^{\pi k}(\gamma J, \gamma' J') = \sum_{M,M',q} \left| \left\langle \gamma J M \left| O_q^{\pi(k)} \right| \gamma' J' M' \right\rangle \right|^2 \tag{9}$$

where γJM and $\gamma' J' M'$ denote lower and upper states, respectively. The transition operator $O^{\pi(k)}$ which describes each multipole is a spherical tensor operator of rank k and parity π. A transition probability that occurs between an upper state $\gamma' J' M'$ and lower state γJM (emission transition) can be described as

$$A^{\pi k}\left(\gamma' J', \gamma J\right) = 2c_k \left[\alpha \left(E_{\gamma' J'} - E_{\gamma J}\right)\right]^{2k+1} \frac{S^{\pi k}(\gamma' J', \gamma J)}{g_{J'}} \tag{10}$$

where $g_{J'}$ is statistically weight of upper level $(g_{J'} = 2J' + 1)$ and c_k is

$$c_k = \frac{(2k+1)(k+1))}{k\left((2k+1)!!\right)^2} . \tag{11}$$

The absorption oscillator strength is

$$f^{\pi k}(\gamma J, \gamma' J') = \frac{1}{\alpha} c_k \left[\alpha \left(E_{\gamma' J'} - E_{\gamma J}\right)\right]^{2k-1} \frac{S^{\pi k}(\gamma J, \gamma' J')}{g_J} . \tag{12}$$

A similar expression can be written for the emission oscillator strength where $\gamma J'$ and γJ are interchanged, making the emission oscillator strength negative. The weighted oscillator strength, or gf value, is completely symmetrical (except sign) between the two levels. The weighted oscillator strength is given

$$gf^{\pi k}(\gamma J, \gamma' J') = g_J f^{\pi k}(\gamma J, \gamma' J') . \tag{13}$$

If the parity of two levels are denoted by π and π', then the electric multipole operator is in the form

$$E^k : \frac{\pi'}{\pi} = (-1)^k . \tag{14}$$

The electric dipole transition (E1) is taken in the levels of different parity.

3. Results and discussion

In this paper, wavelengths, weighted oscillator strengths and transition probabilities for the electric dipole transitions (E1) between $1snl$ ($1 \leq n \leq 9$, $0 \leq l \leq 3$), $2s^2$, $2s2p$, $2s3s$, $2s3p$, $2p^2$, $2p3s$ and $2p3p$ states for heliumlike magnesium (Mg XI) have been calculated. MCHF atomic structure package [43] including Breit-Pauli relativistic corrections has been used for calculations. We varied some parameter values increasingly in MCHF atomic-structure package (in the calculation of relativistic effects and configuration interaction) so that it can be made the calculations for the configurations above. Otherwise it is almost impossible to make the calculations pointed out. We obtained 2629 possible E1 transitions between selected states. Therefore the new and large-scale data including core-core and core-valance correlation and Breit-Pauli relativistic corrections for heliumlike magnesium are performed.

In Table 1, the results obtained which have comparing values are given. In this table, transitions, wavelengths, λ (in Å), oscillator strengths, f-values, and transition probabilities, A_{ki} (in sn^{-1}) which greater or equal than 10^{11}, are given in first, second, fourth, and sixth columns, respectively and according to increasing our wavelengths. Our results obtained have been only compared with [16], [30], [38], and [40] for shortness. The other works for comparing are indicated below the table with superscript lowercase letter. Our results which have no comparing values in literature are given in Table 2. The weighted oscillator strengths (gf-values) and transition probabilities A_{ki} (in sn^{-1}) which greater or equal than 10^{11} for some new transitions are presented according to increasing n in this table. In Table 1 and Table 2 the numbers in brackets represent the power of ten and the superscript only indicates odd-parity states. In the tables, just a part of the results are given for shortness because data obtained for transitions are too much.

Table 1. Wave lengths, λ, oscillator strengths, f-values and transition probabilities (greater of equal than 10^{11}) A_{ki} for E1 transitions in Mg XI. *The figure in parenthese is a multiplying factor in powers of 10.

Transitions	λ(Å)		f-values		A_{ki} (s^{-1})	
	This work	Other works	This work	Other works	This work	Other works
$1s^2\ ^1S_0$–$1s9p\ ^1P_1^o$	7.11	7.119429[a], 7.11943[b]	1.33(–2)	4.40(–3)[a]	1.75(12)	1.93(11)[a]
$1s^2\ ^1S_0$–$1s8p\ ^1P_1^o$	7.14	7.141548[a], 7.14154996[b]	4.10(–3)	6.31(–3)[a]	5.37(11)	2.75(11)[a]
$1s^2\ ^1S_0$–$1s7p\ ^1P_1^o$	7.18	7.174053[a], 7.177000[b]	5.38(–3)	9.52(–3)[a]	6.97(11)	4.11(11)[a]
$1s2s\ ^3S_1$–$2p3s\ ^3P_2^o$	7.23	7.243300[b]	8.78(–3)	–	1.12(12)	4.10(11)[b]
$1s2s\ ^3S_1$–$2p3s\ ^3P_1^o$	7.23	7.245[b], 7.2483 [d]	1.00(–2)	–	1.28(12)	1.02(12)[b]

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Table 1. (Contd.)

Transitions	λ(Å)		f-values		A_{ki} (s^{-1})	
	This work	Other works	This work	Other works	This work	Other works
$1s3s\ ^3S_1$–$2s3p\ ^3P_1^o$	8.44	8.440000[b], 8.4399[d]	4.48(–2)	–	4.19(12)	5.57(12)[b], 4.97(12)[d]
$1s3s\ ^3S_1$–$2s3p\ ^3P_0^o$	8.44	8.440000[b]	4.82(–2)		4.51(12)	5.21(12)[b], 3.10(12)[d]
$1s2p\ ^1P_1^o$–$2p^2\ ^1S_0$	8.44	8.4441[b], 8.4443[d]	2.15(–1)		2.02(13)	1.89(13)[d]
$1s3p\ ^3P_2^o$–$2p3p\ ^3D_3$	8.45	8.445[b]	1.27(–1)	–	1.19(13)	9.35(12)[b]
$1s3p\ ^3P_1^o$–$2p3p\ ^3D_2$	8.45	8.463600[b], 8.4620[d]	9.02(–2)	–	8.42(12)	7.00(12)[b]
$1s3p\ ^3P_1^o$–$2p3p\ ^3D_1$	8.45	8.466000[b], 8.4644[d]	4.15(–2)	–	3.87(12)	4.10(12)[b]
$1s3p\ ^3P_0^o$–$2p3p\ ^3D_1$	8.45	8.465800[b], 8.4642[d]	5.30(–3)	–	4.95(12)	4.87(12)[b]
$1s3p\ ^1P_1^o$–$2p3p\ ^1P_1$	8.48	8.474900[b], 8.4734[d]	9.62(–2)	–	8.93(12)	1.14(13)[b]
$1s3s\ ^1S_0$–$2s3p\ ^1P_1^o$	8.48	8.4853[b], 8.4846[d]	4.56(–2)	–	4.23(12)	5.92(12)[b], 6.06(12)[d]
$1s3p\ ^3P_2^o$–$2s3s\ ^3S_1$	8.49	8.4939[b], 8.4926[d]	2.00(–2)	–	1.85(12)	2.19(12)[b]
$1s2s\ ^1S_0$–$2s2p\ ^1P_1^o$	8.49	8.491000[b], 8.4944[d]	1.24(–1)	–	1.15(13)	1.25(13)[d]
$1s3p\ ^1P_1^o$–$2s3s\ ^1S_0$	8.49	8.4863[b], 8.4849[d]	3.33(–2)	–	3.09(12)	3.23(12)[b]
$1s2s\ ^3S_1$–$2s2p\ ^3P_2^o$	8.52	8.521[b], 8.5192[d]	1.26(–1)	–	1.16(13)	1.21(13)[d]
$1s2p\ ^3P_2^o$–$2p^2\ ^3P_2$	8.53	8.531300[b], 8.531[d]	2.04	–	1.87(13)	1.18(13)[d]
$1s2s\ ^3P_1^o$–$2p^2\ ^3P_2$	8.53	8.5284[d]	6.84(–2)	–	6.27(12)	6.13(12)[d]
$1s2s\ ^3S_1$–$2s2p\ ^3P_1^o$	8.53	8.523000[b], 8.5227[d]	1.26(–1)	–	1.15(13)	1.21(13)[d]
$1s2s\ ^3S_1$–$2s2p\ ^3P_0^o$	8.53	8.524000[b], 8.5243[d]	1.26(–1)	–	1.16(13)	1.21(13)[d]
$1s2p\ ^1P_1^o$–$2p^2\ ^1D_2$	8.54	8.55[b,d]	2.66(–1)	–	2.43(13)	2.43(13)[d]
$1s2p\ ^1P_1^o$–$2s^2\ ^1S_0$	8.67	8.6684[d]	6.12(–2)	–	5.43(12)	5.03(12)[d]
$1s^2\ ^1S_0$–$1s2p\ ^1P_1^o$	9.17	9.168750[a], 9.168500[b]	2.50(–1)	7.42(–1)[a], 2.42(–1)[b], 7.36(–1)[c]	1.98(13)	1.96(13)[a], 1.97(13)[b], 1.95(13)[c]

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Table 1. (Contd.)

Transitions	λ(Å)		f-values		A_{ki} (s^{-1})	
	This work	Other works	This work	Other works	This work	Other works
$1s2s\ ^1S_0$–$1s9p\ ^1P_1^o$	31.11	31.17895[a]	3.42(–2)	5.40(–3)[a]	2.36(11)	1.24(10)[a]
$1s2p\ ^3P_1^o$–$1s5d\ ^3D_2$	34.93	35.14183[a], 35.113800[b]	2.25(–2)	3.40(–2)[a], 2.02(–2)[b]	1.23(11)	1.10(11)[a], 1.09(11)[b]
$1s2p\ ^3P_2^o$–$1s5d\ ^3D_3$	34.97	35.18494[a], 35.161[b]	3.07(–2)	3.80(–2)[a], 2.70(–2)[b]	1.67(11)	1.46(11)[a,b]
$1s2p\ ^1P_1^o$–$1s5d\ ^1D_2$	35.89	36.07415[a], 36.078 [b]	2.90(–2)	4.37(–2)[a], 2.60(–2)[b]	1.50(11)	1.34(11)[a], 1.33(11)[b]
$1s2s\ ^3S_1$–$1s4p\ ^3P_2$	38.01	37.91840[a], 37.922000[b]	3.41(–2)	5.24(–2)[a], 3.11(–2)[b]	1.57(11)	1.46(11)[a], 1.44(11)[b]
$1s2s\ ^3S_1$–$1s4p\ ^3P_1^o$	38.01	37.92479[a], 37.9307[b]	3.41(–2)	3.14(–2)[a], 3.11(–2)[b]	1.57(11)	1.46(11)[a], 1.44(11)[b]
$1s2s\ ^3S_1$–$1s4p\ ^3P_0^o$	38.02	37.92640[a] 37.922000[b]	3.41(–2)	1.05(–2)[a], 3.11(–2)[b]	1.58(11)	1.46(11)[a], 1.44(11)[b]
$1s2p\ ^3P_0^o$–$1s4d\ ^3D_1$	39.00	39.25577[a], 39.292[b]	4.34(–2)	1.22(–1)[a], 4.09(–2)[b]	1.90(11)	1.77(11)[a,b]
$1s2p\ ^3P_1^o$–$1s4d\ ^3D_2$	39.01	39.26832[a], 39.2346[b]	5.71(–2)	9.18(–2)[a], 5.52(–2)[b]	2.50(11)	2.38(11)[a,b]
$1s2p\ ^3P_1^o$–$1s4d\ ^3D_1$	39.01	39.26855[a], 39.292[b]	3.25(–2)	3.06(–2)[a,b]	1.43(11)	1.32(11)[a,b]
$1s2p\ ^3P_2^o$–$1s4d\ ^3D_3$	39.06	39.32094[a], 39.292[b]	7.82(–2)	1.03(–1)[a], 7.36(–2)[b]	3.42(11)	3.17(11)[a], 3.18(11)[b]
$1s2s\ ^1S_0$–$1s4p\ ^1P_1^o$	39.47	39.33157[a], 39.331[b]	3.67(–2)	9.71(–2)[a], 3.26(–2)[b]	1.58(11)	1.40(11)[a,b]
$1s2p\ ^1P_1^o$–$1s4d\ ^1D_2$	40.21	40.43315[a], 40.437000[b]	7.48(–2)	1.21(–1)[a], 7.24(–2)[b]	3.08(11)	2.95(11)[a,b]
$1s2s\ ^3S_1$–$1s3p\ ^3P_2^o$	50.60	50.43755[a], 50.452000[b]	1.29(–1)	2.10(–1)[a], 1.25(–1)[b]	3.36(11)	3.30(11)[a], 3.27(11)[b]
$1s2s\ ^3S_1$–$1s3p\ ^3P_1^o$	50.63	50.46445[a], 50.4799[b]	1.29(–1)	1.26(–1)[a], 1.25(–1)[b]	3.36(11)	3.30(11)[a], 3.26(11)[b]
$1s2s\ ^3S_1$–$1s3p\ ^3P_0^o$	50.64	50.47117[a], 50.472[b]	1.30(–1)	4.20(–2)[a], 1.25(–1)[b]	3.37(11)	3.30(11)[a], 3.26(11)[b]
$1s2p\ ^3P_0$–$1s3d\ ^3D_1$	52.14	52.59852[a], 52.5972[b]	2.29(–1)	6.77(–1)[a], 2.25(–1)[b]	5.62(11)	5.44(11)[a], 5.42(11)[b]
$1s2p\ ^3P_1^o$–$1s3d\ ^3D_2$	52.16	52.62036[a], 52.559400[b]	2.97(–1)	5.08(–1)[a], 3.04(–1)[b]	7.27(11)	7.34(11)[a], 7.32(11)[b]

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Table 1. (Contd.)

Transitions	λ(Å)		*f*-values		A_{ki} (s^{-1})	
	This work	Other works	This work	Other works	This work	Other works
$1s2p\ ^3P_1^o$–$1s3d\ ^3D_1$	52.16	52.62147[a], 52.553900[b]	1.72(–1)	1.69(–1)[a,b]	4.20(11)	4.08(11)[a], 4.07(11)[b]
$1s2p\ ^3P_2^o$–$1s3d\ ^3D_3$	52.25	52.70884[a], 52.658[b]	4.13(–1)	5.68(–1)[a], 4.06(–1)[b]	1.01(12)	9.74(11)[a], 9.77(11)[b]
$1s2p\ ^3P_2^o$–$1s3d\ ^3D_2$	52.26	52.71940[a], 52.658[b]	9.69(–2)	1.01(–1)[a,b]	2.37(11)	2.43(11)[a], 2.44(11)[b]
$1s2s\ ^1S_0$–$1s3p\ ^1P_1^o$	52.87	52.65297[a], 52.650[b]	1.36(–1)	3.96(–1)[a], 1.32(–1)[b]	3.24(11)	3.18(11)[a,b]
$1s2p\ ^1P_1^o$–$1s3d\ ^1D_2$	54.31	54.71399[a], 54.724000[b]	4.10(–1)	7.01(–1)[a], 4.21(–1)[b]	9.27(11)	9.37(11)[a], 9.38(11)[b]
$1s2p\ ^1P_1^o$–$1s3s\ ^1S_0$	54.81	55.19702[a], 55.205000[b]	5.48(–2)	1.70(–2)[a], 5.13(–2)[b]	1.22(11)	1.12(11)[a,b]
$1s3p\ ^3P_2^o$–$1s4d\ ^3D_3$	148.18	151.3372[a], 151.24[b]	3.67(–1)	4.93(–1)[a], 3.52(–1)[b]	1.11(11)	1.03(11)[a,b]
$1s3p\ ^1P_1^o$–$1s4d\ ^1D_2$	153.30	155.8060[a], 155.83[b]	3.87(–1)	6.31(–1)[a], 3.77(–1)[b]	1.10(11)	1.04(11)[a,b]
$1s3d\ ^1D_2$–$1s4f\ ^1F_3^o$	158.90	154.8947[a], 154.950[a]	5.72(–1)	1.02[a]	1.51(11)	2.02(11)[a]

*Supplementary data including the transitions of $A_{ki} \geq 10^7$ associated with this article can be found in the Editorial Office of *Indian J. Phys.*

[a]Atomic Line List v.2.04 [38], [b]CAMBD Atomic Spectra [40], [c]Lin *et al* [29], [d]Vainshtein and Safronova [16].

Consequently, we report the new and accurate wavelengths, oscillator strengths and transition probabilities for a large number of electric dipole transitions (E1) including the levels $n \leq 9$ in Mg XI. We carried out calculations for much longer list of transitions than given in Tables 1 and 2. A good agreement is seen when our calculation results are compared with other works in Table 1. But, for some $\Delta n = 0$ (especially, for highly excited levels) transitions the agreement is less good due to differences in calculated excitation energies. Therefore large differences in transition energies are responsible for the large oscillator strengths and transition rates. But when the other works is consider, we also see the differences among the other works' data. The accuracy of the experimental the radiative parameters (oscillator strengths, transition probabilities, lifetimes *etc.*) may not be very high and the difference between results from measurements may be larger than the differences between theoretical and experimental results. Moreover we may say that one of the difficulties of the MCHF method in extending it to higher states is to maintain the orthogonality of the orbitals.

We think that our results will be used to interpret the observations and experiments for Mg XI. We also hope that a large number of results obtained will be useful for some researches and, particularly, astrophysical applications.

Table 2. New *gf* and $A_{ki}(s^{-1})$ (greater or equal than 10^{11}) values for E1 transition in Mg XI. *The Figure in parentheses is a multiplying factor in powers of 10.

Transitions	*gf*	$A_{ki}(s^{-1})$
1*s*2*s*–1*s*9*p*		
$^3S_1$–$^3P_0^o$	1.89(–2)	1.39(11)
$^3S_1$–$^3P_1^o$	5.69(–2)	1.39(11)
$^3S_1$–$^3P_2^o$	9.59(–2)	1.41(11)
1*s*2*s*–2*s*3*p*		
$^3S_1$–$^3P_0^o$	1.46(–2)	1.85(12)
1*s*2*p*–1*s*9*d*		
$^1P_1^o$–$^1D_2$	1.15(–1)	1.54(11)
$^3P_2^o$–$^3D_3$	1.35(–1)	1.36(11)
1*s*2*p*–2*s*3*s*		
$^3P_1^o$–$^3S_1$	1.13(–2)	4.68(11)
1*s*2*p*–2*p*(2)		
$^3P_0^o$–$^3P_1$	2.72(–1)	8.33(12)
$^3P_1^o$–$^3P_0$	2.72(–1)	2.49(13)
$^3P_1^o$–$^3P_1$	2.04(–1)	6.24(12)
$^3P_2^o$–$^3P_1$	3.41(–1)	1.04(13)
1*s*2*p*–2*p*3*p*		
$^3P_0^o$–$^3P_1$	2.78(–2)	1.17(12)
$^3P_2^o$–$^3S_1$	5.15(–2)	2.17(12)
1*s*3*p*–1*s*9*s*		
$^1P_1^o$–$^1S_0$	8.79(–2)	1.04(11)
1*s*3*p*–2*s*3*s*		
$^3P_0^o$–$^3S_1$	1.05(–2)	3.22(11)
$^3P_1^o$–$^3S_1$	3.36(–2)	1.04(12)
1*s*3*p*–2*p*3*p*		
$^1P_1^o$–$^3D_1$	8.36(–2)	2.59(12)
$^3P_0^o$–$^3S_1$	5.97(–2)	1.87(12)
$^3P_0^o$–$^1P_1$	4.34(–2)	1.35(12)
$^3P_1^o$–$^1P_1$	4.23(–2)	1.31(12)
$^3P_1^o$–$^3P_1$	6.73(–2)	2.11(12)
$^3P_1^o$–$^3P_2$	2.08(–1)	3.91(12)
$^3P_2^o$–$^3D_1$	1.35(–2)	4.20(11)
$^3P_2^o$–$^3D_2$	1.83(–1)	3.42(12)
1*s*3*d*–1*s*4*f*		
$^3D_1$–$^3F_2^o$	3.00	1.59(11)
$^3D_2$–$^3F_3^o$	3.70	1.40(11)
$^3D_3$–$^3F_4^o$	6.43	1.89(11)

Table 2. Contd. on next column

Table 2. *(Contd.)*

Transitions	*gf*	$A_{ki}(s^{-1})$
1*s*3*d*–2*s*3*p*		
$^1D_2$–$^1P_1^o$	1.99(–2)	6.12(11)
$^3D_1$–$^3P_0^o$	4.35(–3)	4.04(11)
$^3D_1$–$^3P_1^o$	3.44(–3)	1.06(11)
$^3D_2$–$^3P_1^o$	1.00(–2)	3.09(11)
$^3D_3$–$^3P_2^o$	2.15(–2)	3.99(11)
1*s*3*d*–2*p*3*s*		
$^3D_1$–$^3P_0^o$	5.31(–3)	4.95(11)
$^3D_1$–$^3P_1^o$	3.81(–3)	1.18(11)
$^3D_2$–$^3P_1^o$	1.02(–2)	3.18(11)
$^3D_3$–$^3P_2^o$	1.91(–2)	3.56(11)
1*s*4*p*–2*s*3*s*		
$^1P_1^o$–$^1S_0$	1.47(–3)	1.22(11)
1*s*4*p*–2*p*3*p*		
$^1P_1^o$–$^1S_0$	1.75(–3)	1.49(11)
$^1P_1^o$–$^1D_2$	1.24(–2)	2.08(11)
$^1P_1^o$–$^1P_1$	3.66(–3)	1.01(11)
$^3P_1^o$–$^3P_0$	1.83(–3)	1.54(11)
$^3P_2^o$–$^3P_2$	6.73(–3)	1.13(11)
1*s*4*d*–2*s*3*p*		
$^3D_1$–$^3P_0^o$	1.89(–3)	1.57(11)
$^3D_2$–$^3P_1^o$	4.30(–3)	1.19(11)
$^3D_3$–$^3P_2^o$	8.73(–3)	1.45(11)
1*s*4*d*–2*p*3*s*		
$^1D_2$–$^1P_1^o$	4.18(–3)	1.17(11)
2*s*(2)–2*p*3*s*		
$^1S_0$–$^1P_1^o$	2.09(–1)	2.22(11)
2*s*(2)–2*s*3*p*		
$^1S_0$–$^1P_1^o$	4.84(–1)	4.65(11)
2*s*2*p*–2*s*3*s*		
$^3P_1^o$–$^3S_1$	1.30(–1)	1.18(11)
$^3P_2^o$–$^3S_1$	2.10(–1)	1.90(11)
2*s*2*p*–2*p*3*p*		
$^1P_1^o$–$^1S_0$	1.73(–1)	4.88(11)
$^1P_1^o$–$^1P_1$	3.74(–1)	3.04(11)
$^1P_1^o$–$^1D_2$	7.49(–1)	3.92(11)

Table 2. *Contd.*

Transitions	gf	$A_{ki}(s^{-1})$
$^3P_0^o$–$^3P_1$	1.44(–1)	1.43(11)
$^3P_0^o$–$^3D_1$	2.13(–1)	2.04(11)
$^3P_1^o$–$^3P_0$	1.45(–1)	4.30(11)
$^3P_1^o$–$^3P_1$	1.40(–1)	1.39(11)
$^3P_1^o$–$^3D_1$	1.33(–1)	1.27(11)
$^3P_1^o$–$^3D_2$	5.84(–1)	3.36(11)
$^3P_2^o$–$^3S_1$	1.37(–1)	1.37(11)
$^3P_2^o$–$^3P_1$	1.41(–1)	1.39(11)
$^3P_2^o$–$^3P_2$	5.66(–1)	3.36(11)
$^3P_2^o$–$^3D_3$	1.04	4.28(11)
$2p(2)$–$2p3s$		
$^1S_0$–$^1P_1^o$	2.33(–1)	1.80(11)
$^1D_2$–$^1P_1^o$	1.24(–1)	1.12(11)

*Supplementary data including the transitions of $A_{ki} \geq 10^7$ associated with this article can be found in the Editorial Office of *Indian J. Phys.*

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